Advanced Fabrication Processes for Superconducting Very Large Scale Integrated Circuits

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Abstract— We review the salient features of two advanced nodes of an 8-Nb-layer fully planarized process developed recently at MIT Lincoln Laboratory for fabricating Single Flux Quantum (SFQ) digital circuits with very large scale integration (VLSI) on 200-mm wafers: the SFQ4ee and SFQ5ee nodes, where "ee" denotes the process is tuned for energy efficient SFQ circuits. The former has eight superconducting layers with 0.5 μm minimum feature size and a 2 Ω/sq Mo layer for circuit resistors. The latter has nine superconducting layers: eight Nb wiring layers with the minimum feature size of 350 nm and a thin superconducting MoN_x layer (T_c ~ 7.5 K) with high kinetic inductance (about 8 pH/sq) for forming compact inductors. A nonsuperconducting (T_c < 2 K) MoN_x layer with lower nitrogen content is used for 6 Ω/sq planar resistors for shunting and biasing of Josephson junctions (JJ). Another resistive layer is added to form interlayer, sandwich-type resistors of mΩ range for releasing unwanted flux quanta from superconducting loops of logic cells. Both process nodes use Au/Pt/Ti contact metallization for chip packaging. The technology utilizes one layer of Nb/AlO_x-Al/Nb JJs with critical current density, J_c of 100 μA/μm^2 and minimum diameter of 700 nm. Circuit patterns are defined by 248-nm photolithography and high density plasma etching. All circuit layers are fully planarized using chemical mechanical planarization (CMP) of SiO_2 interlayer dielectric. The following results and topics are presented and discussed: JJ fabrication, the effect of surface topography under the JJs on the their properties and repeatability, I_c and J_c targeting, effect of hydrogen dissolved in Nb, circuit inductors, MoN_x properties for the resistor layer and for high kinetic inductance layer, technology of mΩ-range resistors.

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Keywords (Index Terms)— Josephson junctions, kinetic inductance, MoN_x, Nb/AlO_x/Nb Josephson junctions, ERSFQ, RSFQ, RQL, SFQ digital circuits, superconductor integrated circuits.